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Report No. UT-08.01

VARIABLE SPEED LIMIT SIGNS EFFECTS ON SPEED AND SPEED VARIATION IN WORK ZONES

Prepared For:

Utah Department of Transportation
Research and Innovation Division

Submitted by:

InterPlan Co.

Authored by:

Matt Riffkin P.E., Thomas McMurtry, Suellen Heath, Misuru Saito Ph.D.

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16. Abstract

Technological advances allow speed limits to be changed in real time based on actual roadway conditions. There may be potential advantages to using variable speed limits in Utah, such as for traffic control during construction where the speed limit may be lowered adjacent to actual construction activities versus at other times or locations within an established work zone. This research will test the compliance and derive potential advantages from the use of variable speed limit equipment.

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EXECUTIVE SUMMARY

Variable Speed Limit (VSL) signs are used across the country to lower posted speed limits in certain areas. They allow for operators to adjust the posted speed limit without changing the physical sign. They are used in conjunction with Intelligent Transportation Systems to lower speed limits for several reasons including: congestion, construction, accidents, fog, snow, and ice. As technology advances, the ease of use of VSL signs is also increasing, as the speeds can now be changed remotely via email or telephone, at pre-set times of day, or manually. In the near future, VLS signs may be used to alter speed limits based on real time traffic or weather conditions.

The purpose of this research is to test the use of this technology in Utah. In addition to the use of signs, a review of UDOT Administrative Rules governing the establishment of speed limits was also addressed to ensure that UDOT is in a position to appropriately take advantage of this evolving technology. However, the primary focus of this research was geared towards driver response to VSL sign usage. A single test site consisting of a relatively long duration and long distance work zone on I-80 north of Wanship, Utah was used to test the response of driver speeds using VSL signs.

Based on this test, the response and long term application of VSL signs is very positive. Both the average speed and variation in speeds were reduced by providing drivers real time speed limit information which reacted to the construction conditions in the field. The net result of lower speed variations, as well as lower speeds where conditions require, should result in improved safety to highway users and construction personnel. Long term use of VSL signs is recommended for further application in Utah.

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1 INTRODUCTION

1.1 Background

Variable Speed Limit (VSL) signs are used across the country to lower posted speed limits in certain areas. They allow for operators to adjust the posted speed limit without changing the sign. They are used in conjunction with Intelligent Transportation Systems to lower speed limits for several reasons including congestion, construction, accidents, fog, snow, and ice. VSL signs have been successfully tested by several state departments of transportation such as Washington and New Jersey.

Utah Department of Transportation (UDOT) Research wanted to test the use of VSL signs in conjunction with a construction project. Long construction zones often have actual construction occurring in only short segments of the zone. In addition, construction zones are signed using static speed limit signs as if construction activity occurs throughout the entire day on each and every day. In reality, the intensity, duration, and location of construction activity varies throughout the construction zone depending on the extent of work being performed. Providing more accurate and real time speed restrictions based on the level of construction activity provides more accurate information to motorists and can allow drivers to comply with the posted regulatory speed while improving safety in the construction zone.

Reducing vehicle speeds in construction zones improves safety for drivers and construction workers and can reduce the severity of accidents which occur in the zone. “Normally, crashes involving vehicles traveling at high speed are more severe than those at low speed.” (*A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials (ASSHTO), 2004: Page 102)

Reducing the speed of individual drivers is important, however, reducing the variation of speed of all drivers in a section of roadway has an even greater safety enhancing effect. “Crashes are not related as much to speed as to the range in speeds from the highest to the lowest.” (ASSHTO, 2004: Page 102). Reducing speed deviation amongst vehicles also contributes to increased safety. “Studies show that, regardless of the average speed on the highway, the more a vehicle deviates from the average speed, the greater its chances of becoming involved in a crash.” (ASSHTO, 2004: Page 239). Finally, areas of high truck volume are of particular interest with regard to reducing average speed and speed deviation of all vehicles.

Figure 1-1: Relationship between Crash Rate of Trucks and Speed

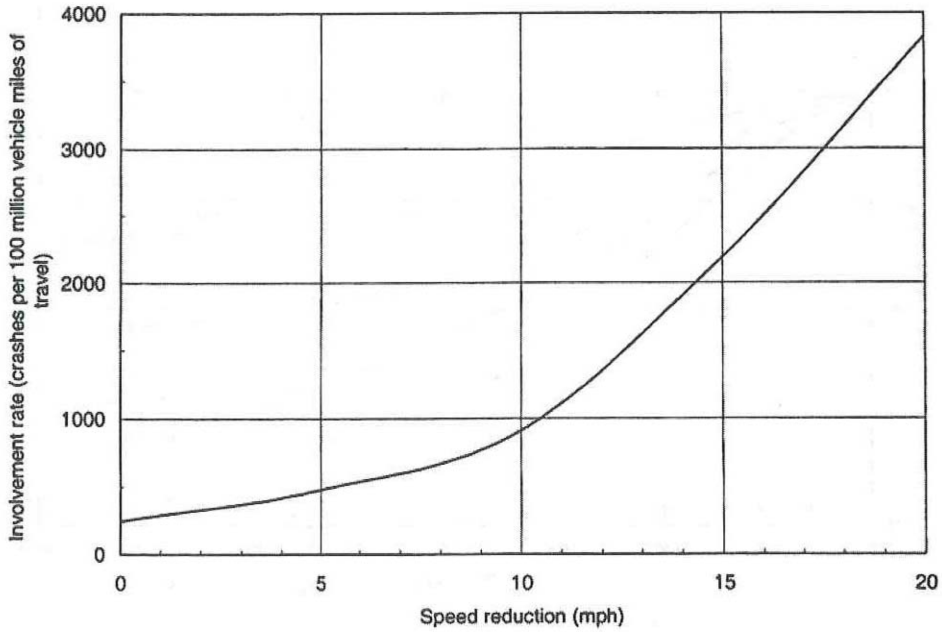
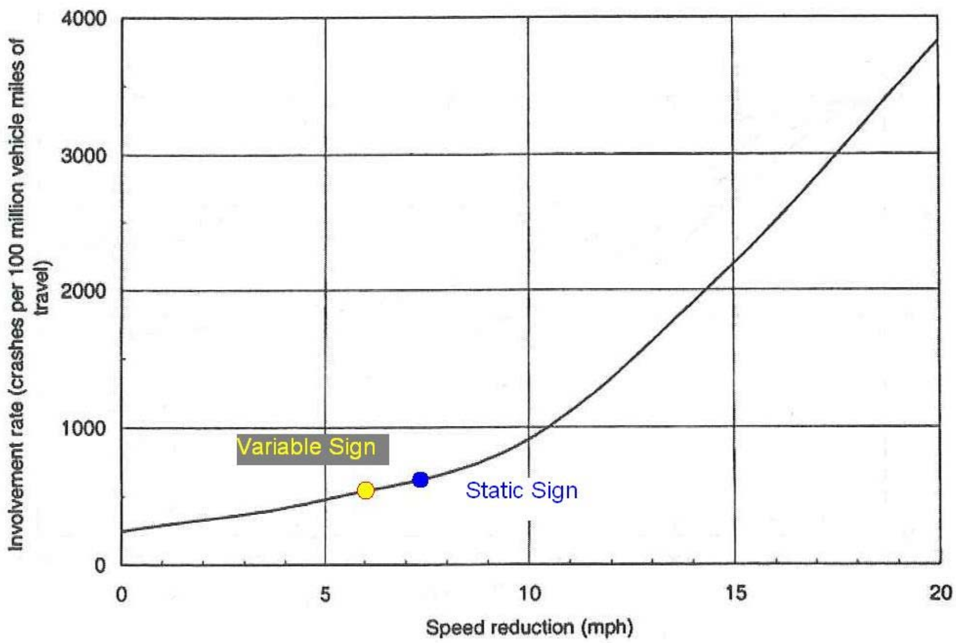


Exhibit 3-58. Crash Involvement Rate of Trucks for Which Running Speeds Are Reduced below Average Running Speed of All Traffic (41)

Source: AASHTO, 2004: Page 239

Figure 1- 2: Speed Reduction Observed in this Study



1.2 Purpose

The purpose of this research project is to investigate the use of VSL signs for application in the State of Utah. In this study we will attempt to answer the question, "Would the use of VSL signs better control the variability of vehicle speeds by providing drivers with more accurate information, particularly during construction periods?"

A secondary purpose of this research project is to examine the policies for determining posted speed limits and for adjusting the existing speed limits in construction zones. The establishment of Speed Limits on State Highways and the establishment of Work Zone Speed Limits are documented in UDOT Administrative Rules 06C-25 and 06C-61, respectively.

1.2.1. Literature Review

In our test, two VSL signs were set with speed limits based on a pre-determined schedule varying by week and/or by day/night time. In other studies, VSL signs utilize traffic speed and volume detection, weather information, and road surface condition technology to determine appropriate speeds for drivers, and display them on overhead or roadside variable message signs.

Washington's DOT has a VSL system on a mountain pass on I-90 which responds to weather conditions to advise motorists of safe travelling speed limits. And, they have instituted a VSL system on a 23 mile section of US-2 which alters speed due to road conditions. Washington also uses VSL for work zones, for example on I-5 at the SR 502 Interchange construction zone speed limits were changed from 70 mph to 60 mph.

Many other transportation entities have utilized this technology to reduce speeds on roads. On the New Jersey Turnpike 120 signs collect speed and volume data and display variable speed limits based on accidents, congestion, construction or weather. New Mexico had a VSL system on an urban section of I-40 from 1989 to 1998 which used traffic speed, day versus night and precipitation to determine safe speed limits. In Colorado on I-70 at the Eisenhower Tunnel, VSL technology weighs downhill travelling vehicles and advises trucks to alter their speed. "Since system deployment, truck-related accidents have declined on the steep downhill grade sections while the volume of truck traffic has increased by an average of 5 percent per year." (*Speed Management Workshop*, TRB January 2000, safety.fhwa.dot.gov/tools/docs/vslexamples.ppt) Oregon also uses a similar system for downhill trucks on I-84. Minnesota used VSL in work zones on I-494 in the Twin Cities area to decrease upstream traffic speed from 65 mph to 45 mph when drivers approach the work zone bottleneck. There are also numerous examples of non-US countries using this technology.

Some of the documented VSL usage appears to be aimed at increasing vehicles' speed by giving drivers confidence that faster speeds are safe in conditions where they expect multiple slow-downs due to construction and congestion. A VSL test case was undertaken on I-96 in Michigan *"A Field Test and Evaluation of Variable Speed Limits in Work Zones"* (U. S. Department of Transportation Federal Highway Administration, December 2004). In this study, VSL was used to improve traffic flow through a work zone by providing more realistic speed limits which would enable vehicles to travel at increased speeds and minimize delay. The regulatory speed limit in the work zone was 50 mph versus 70 mph normally. This study found that the average speed of motorists did increase, and travel time decreased when the VSL was operating.

1.3 Hypothesis

Improved safety to motorists and construction personnel occurs when drivers follow predictable patterns and speeds. Speed limit signs which vary the limit based on prevalent conditions will have greater compliance than static signs. This compliance will result in more drivers traveling within the posted speed limit and fewer drivers traveling either significantly faster or slower than the posted speed.

1.4 Data Collection

Vehicle speed data was collected at five locations on westbound I-80 for all hours of the day. The data was collected from July 10, 2007 through September 29, 2007. Data was collected by L2 Data Collection using Jamar tube counters.

1.5 Report Organization

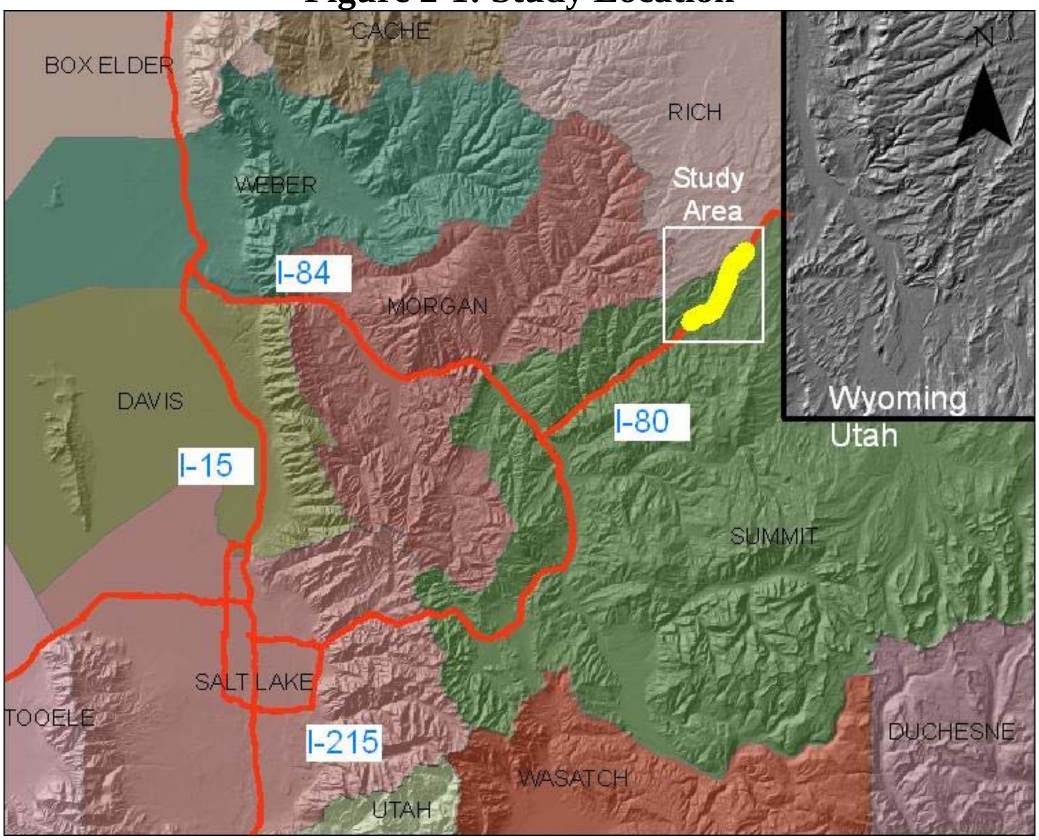
This report consists of four chapters: 1) Introduction, 2) Methodology, 3) Study Findings, and 4) Conclusions and Recommendations. References and an Appendix follow these chapters.

2 STUDY METHODOLOGY

2.1 Study Site Location

The study site is located on I-80 in Summit County near the Utah-Wyoming Border. This study location is in UDOT Region 2 and was chosen as an active construction area. There was a pavement “crack and seal” project on I-80, from mile post 185 to 191, Castle Rock to Wasatch. The Region 2 resident engineer volunteered this construction project to test the use of VSL signs. Figure 2-1 displays the study area location on a regional map.

Figure 2-1: Study Location



Source: GIS data from Utah Automated Geographic Reference Center (AGRC)

2.2 Construction Project Description

The construction project on I-80 is a single crack and seal project with lane closures in both the eastbound and westbound directions. The construction project was conducted by WW Clyde under the direction of UDOT Region 2. Eastbound and westbound travel was restricted to one lane in the project area at all hours through the completion of the project, October 2007. For this research project only westbound traffic was used due to steep grades slowing the traffic on the eastbound lanes.

2.3 Selection of VSL Signs

This research project included the purchase of two VSL signs. For the purchase of the signs, InterPlan Co. asked for cost bids from competing firms. VSL sign specifications were detailed before bids were requested so that the signs were appropriately compared. Table 2-1 below lists the sign specifications. Some items were required for the selection of signs and others were desirable.

Table 2- 1: Specifications

Requirements for this study	Desirables
VSL sign must be able to change speed limit displayed on sign	Universal mounting system
Sign must follow MUTCD standards	Fully portable compact trailer
30 inch x 36 inch MUTCD standard “Speed Limit” sign	Training on how to operate
18 inch high by 12 inch wide number	Delivery to location
2 digit display	
Electronic display	
216 LED pixels: 595nm Amber or White	
30 degree viewing angle	
100,000 hours service life	
Black background	
Two pair of 6 Volt 235 Amp HR sealed Battery	
Programmable box on site, including display, data logging	
120 Watt Solar Pkg. (Panel, controller, mounting bracket)	

Four firms were contacted for bids, however two firms, including Daktronics, did not submit bids. These firms felt that they could not competitively bid on the item because it would require a special job for them to create the signs. Ultimately two bids were received and considered. The two bids came from International Road Dynamics and K&K Systems. A side by side comparison of the two bids is shown in Table 2-2.

Table 2- 2: Comparative Bids

Vendor	International Road Dynamics	K&K Systems
Cost	$20,710	$17,756
Power	Solar 4 6V batteries	Solar 4 6V batteries
Trailer	Compact white	Compact orange
Software/Other	No data logging	Speed data logging

The K&K Systems sign was chosen because it was $3,000 less expensive and provided adequate quality. This system also included speed data logging, which was not used in the test period since speed tubes were used. A photograph of the K&K Systems sign that was purchased is pictured in Figure 2-2.

Figure 2-2: Variable Speed Equipment

Photo by Thomas McMurtry, July 2007

2.4 Lessons Learned in Purchase

The signs that were purchased met the expectations for a VSL sign. They are easy to use, and the posted speed limit is changed by adjusting a thumb wheel inside the box (see Figure 2-3). There is one feature that would have been nice to have on the signs and should be considered in future purchases. In this sign, the speed limit had to be changed by hand on site. There are options to upgrade the sign to include a timing device for speed changes so that it could be set to change every day at 6:00 PM, for example. There are also services available that allow for the sign to be changed remotely using cellular phone signals or satellite signals. This could be a useful feature. The location used for this study did not have reliable construction schedules and did not have cellular service, so these features were not purchased but could be upgraded in the future.

Figure 2-3: Thumb Wheel Setting

Photo by Thomas McMurtry, July 2007

2.5 Data collection

This research project involved an extensive amount of data collection. Speed data was collected for vehicles at widespread locations in the study area. Five locations were identified as needed to collect sufficient speed data. Two methods of speed data collection were considered.

2.5.1. Collection Method Selected

Traffic counting tubes were used due to accuracy of defined speed bins, although maintenance requirements were high. L2 Data Collection performed the data collection at the five locations. They were responsible for the maintenance of tubes and counters. There were several occasions when the tubes were removed for paving or were torn out by traffic. The data missed during those times was anticipated and the data collection period was set at 12 weeks to account for losses and to accurately count all roadway scenarios.

2.5.2. Collection Methods Not Selected

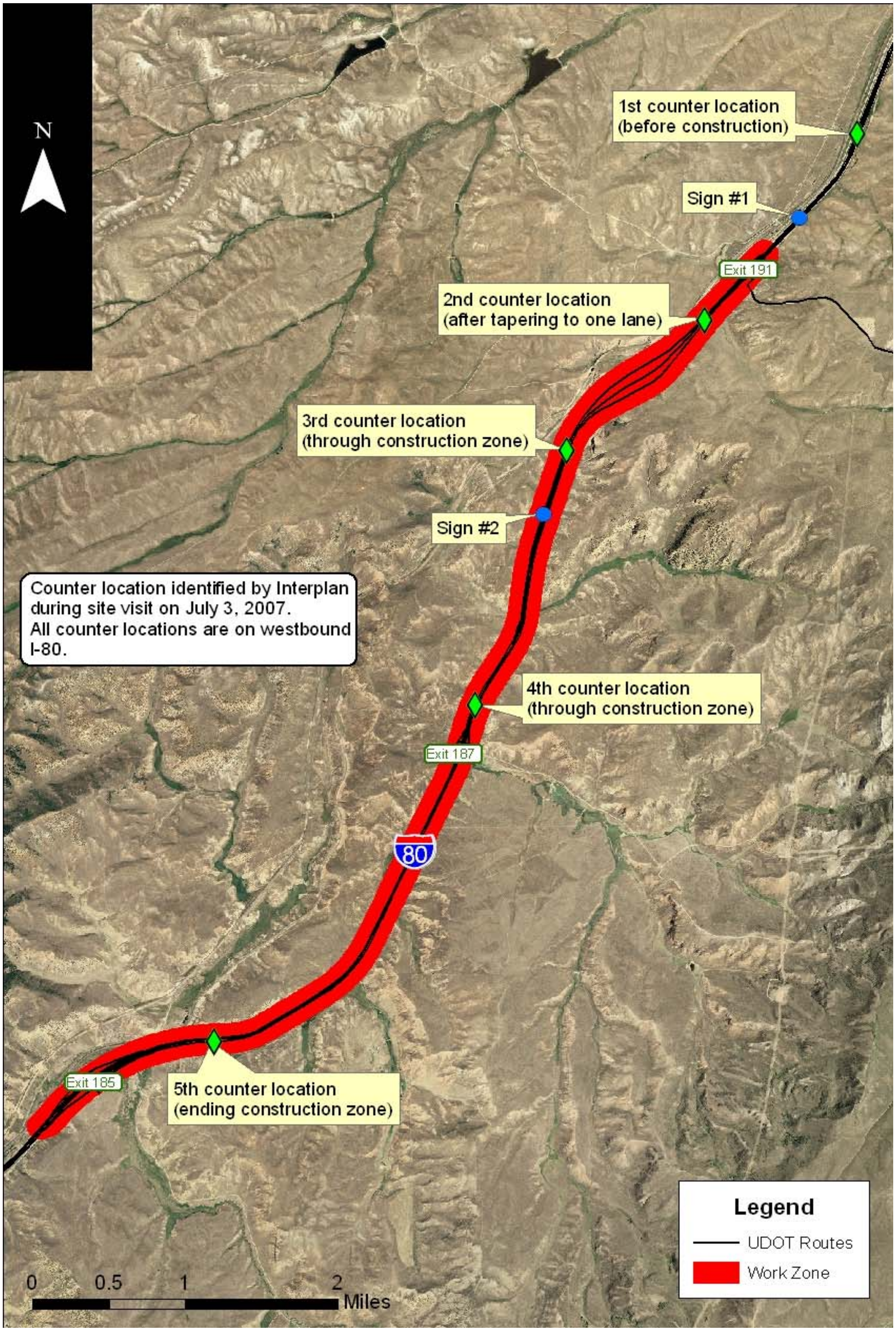
Wavetronix with Digital Wave Radar was explored, but ultimately not used due to data collection restrictions and cost. The VSL signs purchased also have the capability of measuring the travel speed of the vehicles – but only at the location of the signs, which did not fit into the design of this project. Also there was three weeks of data collected before the signs were in place.

2.5.3. Data Collection Locations

As previously mentioned, five locations were identified as speed data collection points. Five points were chosen to give a representative spectrum of the traveling speeds under multiple conditions of the construction zone.

The first counter was placed before the construction to capture vehicles under normal conditions. The second counter was placed at the beginning of the construction zone just after the roadway was tapered down to one lane. The third and fourth counters were placed through the construction zone, in no particular specific location, but spaced about a mile and a half apart. The fifth counter was placed near the end of the construction zone where there was still only one lane open, but not in active construction. Figure 2-4 is a map of the study area with the speed counter locations and VSL sign locations identified.

Figure 2-4: Site Map



Source: GIS data from Utah Automated Geographic Reference Center (AGRC)

2.5.4. Data Collection Scenarios

For the purpose of this study, two VSL sign conditions were tested against the existing sign condition. Thus, data was collected under three different signing conditions. The three signing conditions were:

- Standard 65 MPH speed limit signs
- VSL sign posted at 65 MPH 24 hours per day, 7 days per week
- VSL sign varying between 55 MPH during the day and 65 MPH at night

Data was collected for the standard sign for the first three weeks of the testing period. Following that, the two VSL conditions were alternated in two week blocks. The schedule of the data collection under the different signing conditions is displayed in the calendar in Figure 2-5.

The signing conditions are color coded in the schedule and the graphs which follow. Days where standard 65 MPH speed limit signs were used are shown in light blue. Days where VSL signs posted at 65 MPH were used are shown in yellow. Days where VSL signs varied between 55 MPH during the construction periods of the day and 65 MPH at night are shown in pink.

Figure 2-5: Schedule

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
JULY						
CONSTRUC-TION ON-GOING	2	3	4	5	6	7
8	STANDARD SIGN 65 MPH 24/7	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
AUGUST						
29	30	VSL 65 MPH 24/7	2	2	3	4
5	6	7	8	9	10	11
12	VSL 65 MPH NIGHT 55 MPH DAY	14	15	16	17	18
19	20	21	22	23	24	25
SEPTEMBER						
VSL 65 MPH 24/7	27	28	29	30	31	1
2	3	4	5	6	7	8
9	VSL 65 MPH NIGHT 55 MPH DAY	11	12	13	14	15
16	17	18	19	20	21	VSL 65 MPH 24/7
23	24	25	26	27	28	29

3 STUDY FINDINGS

3.1 Data Points

Five tube counters collecting speed data for each vehicle that traveled through the construction zone for 12 weeks, or approximately 80 days, generated a great deal of data. Table 3-1 shows the number of vehicles speeds that were collected at each counter locations throughout the research project. Overall, almost three million data points were collected and analyzed.

Table 3-1: Data Points

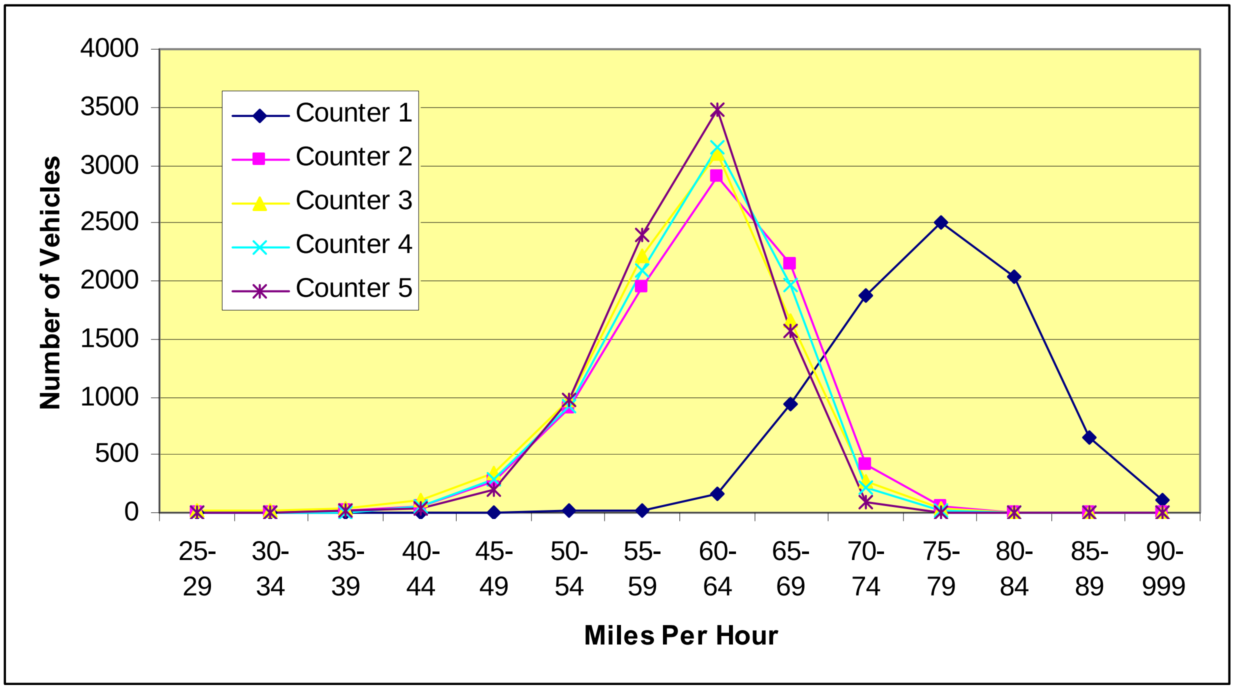
Counter Location	1	2	3	4	5
Number of Vehicles Counted	627,585	549,686	536,823	560,546	546,781

The data was collected in five mile per hour intervals for each hour of day throughout the duration of the study. Analysis could be performed, therefore, to answer the question, for example, "How many vehicles traveled between 55 to 59 MPH on Tuesday from 9 AM to 10 AM at counter number 3?" Data indicating the type of vehicle, truck, trailer, RV, motorcycle, etc. was not collected. Periods where data was not collected, generally due to equipment malfunction when tubes were stripped off the pavement, occur randomly by date, by time of day and by counter.

3.2 Speed Distribution

The distribution of speeds observed at various counters in general followed an expected bell curve (see Figure 3-1 for sample speed distributions at counter 1 and 2). Some vehicles travel less than the posted speed limit and some more, but the majority of vehicles travel within a range of 15 mph of each other. On Friday, August 25, Counter 1, located before the construction area, had a static posted speed limit of 75 mph. Counter 2 was located just after a VSL sign of 55 mph during the day and 65 mph at night when variable speed limits were used.

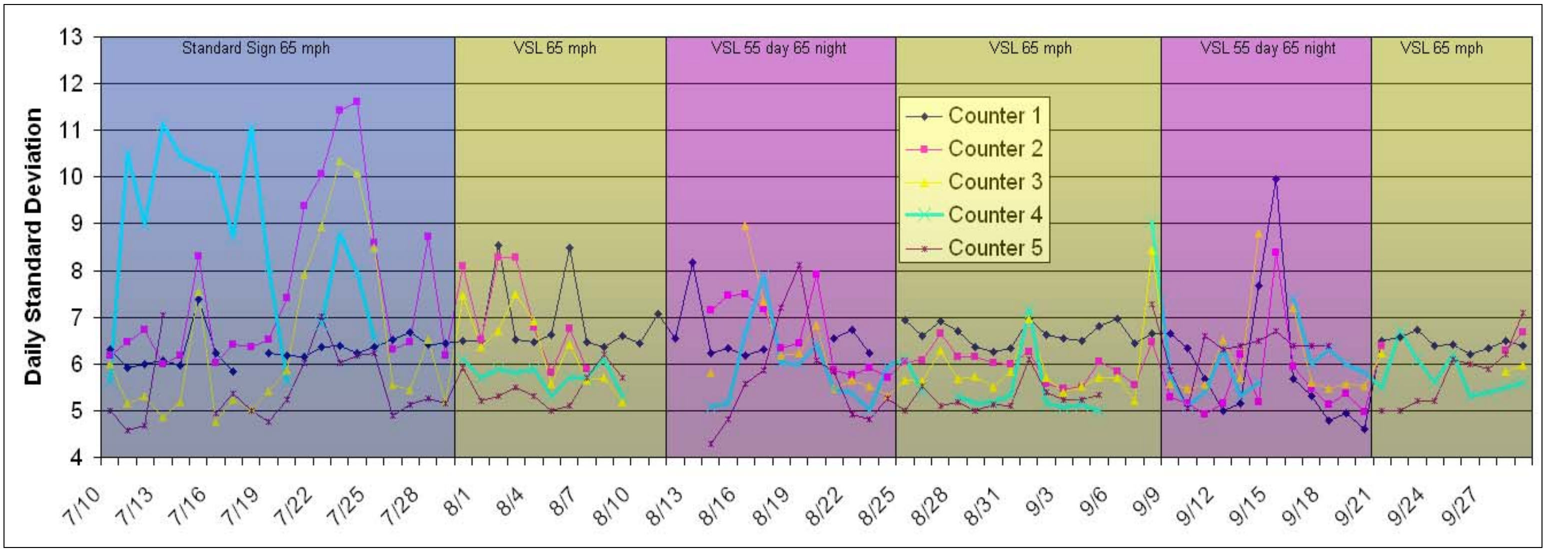
Figure 3-1: August 30, 2007 24 Hour Speed Data
Counters 2 thru 5 65 mph speed limit 24/7



This day and these counters, chosen at random, are typical of the data collected in this study.

3.3 Standard Deviation of the Data

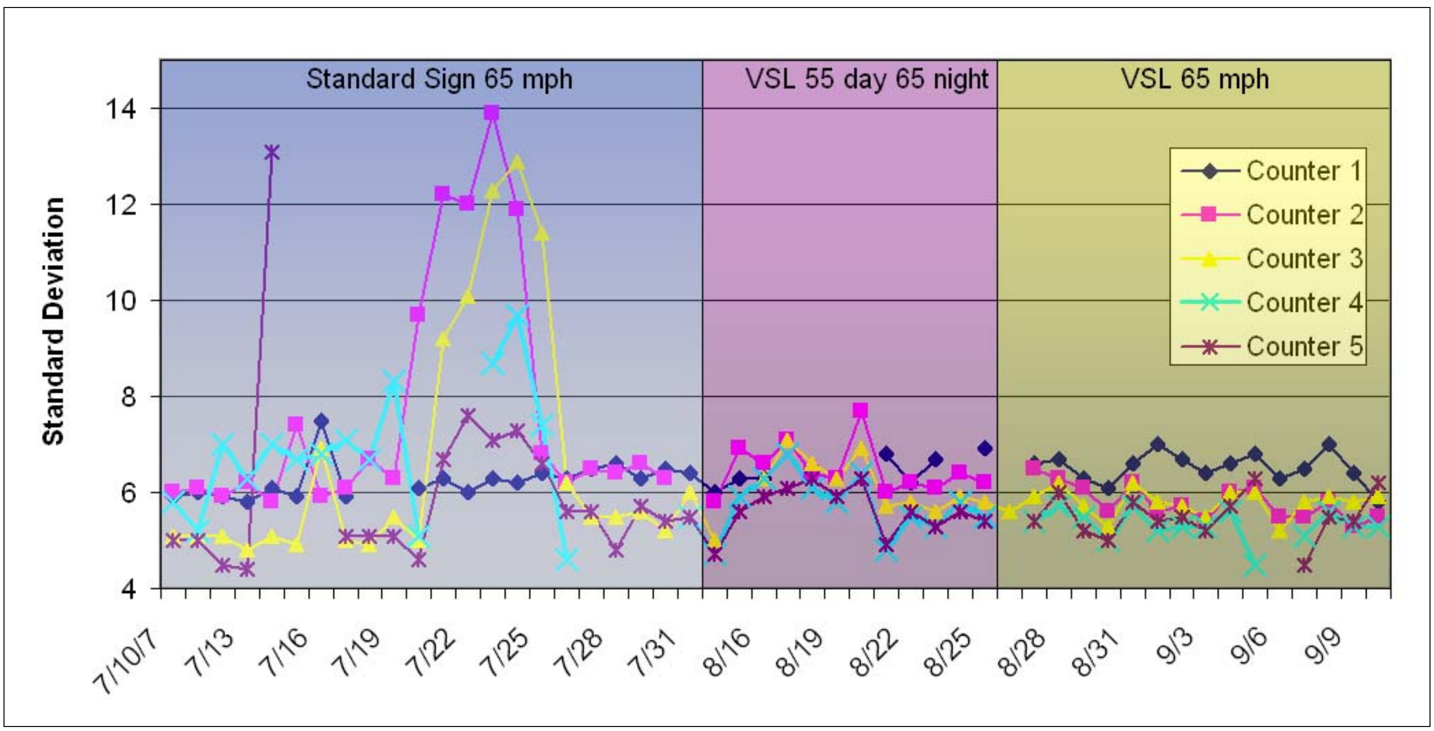
Figure 3-2: Standard Deviation of Speed



When examining the daily standard deviation of speed one sees that for the most part, Counter 1 has greater standard deviation than the other counters. On July 31, the variable speed signs were installed. After installation of the variable signs, for the 50 days with complete data, Counter 1 has the highest standard deviation 31 days, or 62% of the time. During the period between August 13 and 20 and during the period of September 10 through 20, Counter 1's standard deviation is lower than the other counters. This may be because construction on those days was such that traffic was frequently interrupted, leading to greater deviation in speed.

The pattern of construction slow-downs during the day could not be separated from the data in any methodical way. The existence of wide speed fluctuations during heavy construction created greater standard deviation in the data than expected. This study sought to compare the variability of speeds under different speed limit sign conditions. Therefore, to examine speed variation in the absence of construction interruptions, the nighttime, from 7pm to 6am standard deviation was analyzed.

Figure 3-3: Nighttime Standard Deviation of Speed

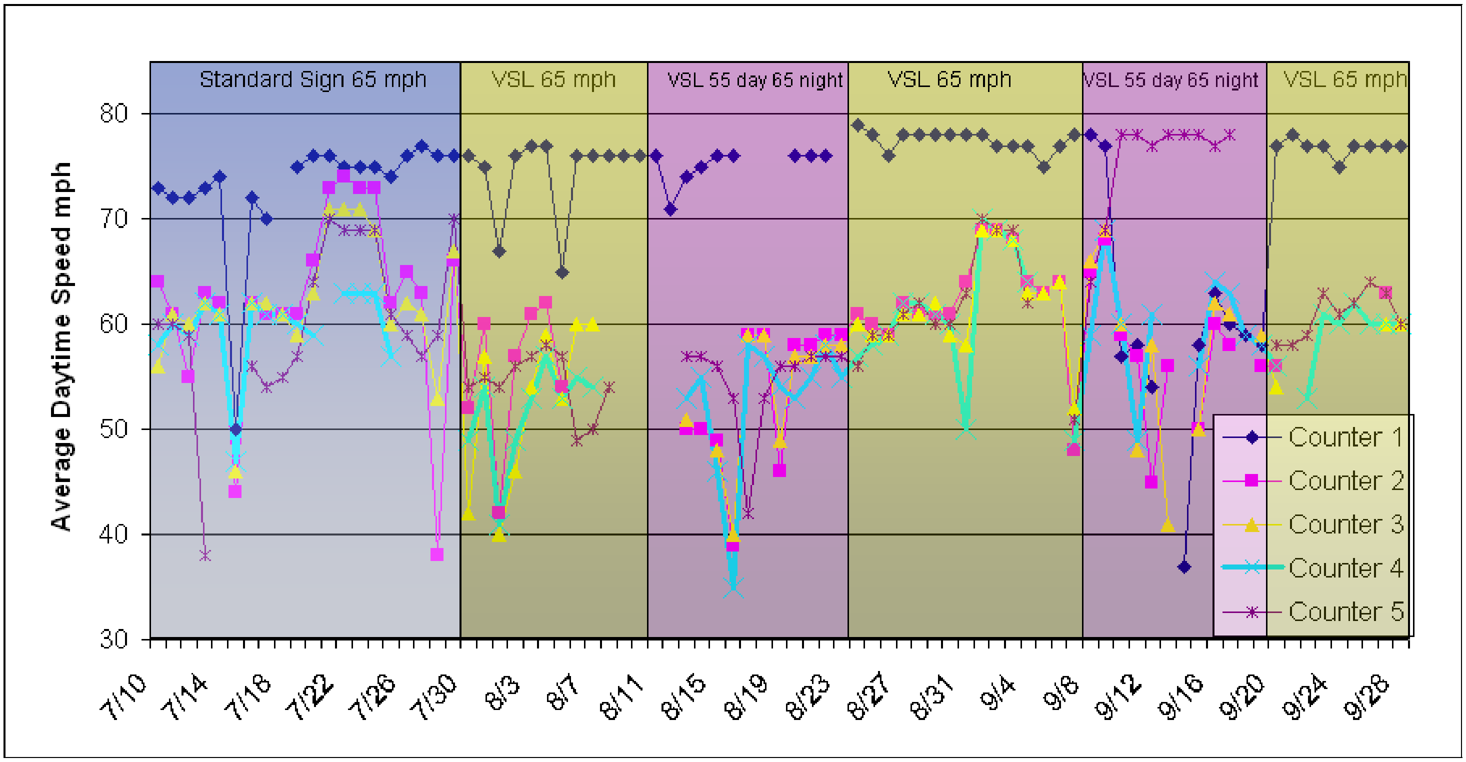


Nighttime standard deviation was highest at Counter 1 when VSL signs were present. Of the 22 days with complete data from August 13 through September 9, Counter 1 has the highest standard deviation for 16 days, or 70%.This is a slightly higher percentage of occurrences than found measuring full day periods.

Before the installation of VSL signs, Counters 2 through 5 had speeds whose daily standard deviation ranged from 4.3 to 14. In these locations, after variable signs are installed, the highest daily speed standard deviation was 7.9. The graph also demonstrates that during the Variable Speed Limit sign period set to 65 mph, standard deviation for Counters 2 through 5 was higher than 6 mph on only 3 occurrences. This low standard deviation of average speeds indicates that few vehicles are moving either much faster or slower than other vehicles. The majority of vehicles are traveling at the speeds very similar to each other.

3.4 Average Speed

Figure 3-4: Daytime Average Speed July 10 to September 28

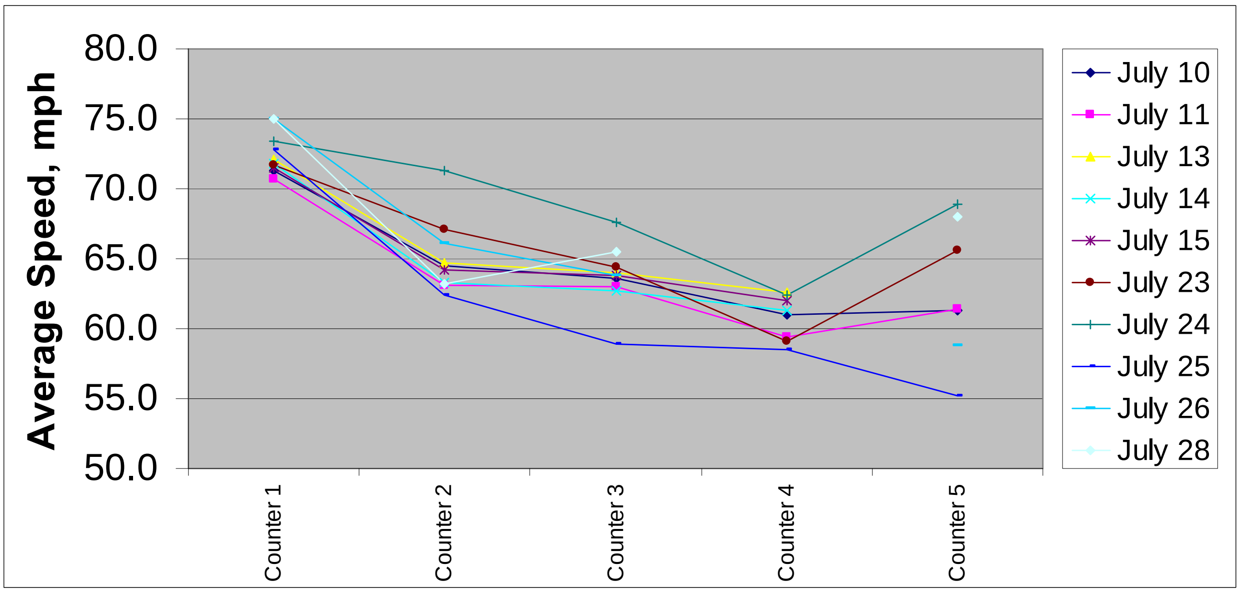


Daily average speeds at Counters 2 through 5 are less than Counter 1 for the entire study period except a short period in September as shown in Figure 3-4. Slow speeds at Counter 1 may be due to congestion just upstream of the work zone. Counter 5 experienced very high average speeds during that period, and other counters exhibit average speeds lower than other periods. Increased speeds at Counter 5 may reflect vehicles speeding up significantly to make up for time lost in congestion.

3.4.1. Nighttime Average Speed

In order to evaluate the differences in the effect of VSL signs without the effects of construction work, average speeds at night hours from 7:00 PM to 8:00 AM of the next day at the five counter locations were plotted. With static 65 mph reduced speed work zone signs average speeds vary as shown in Figure 3-5. The standard deviation of the mean speeds at each counter location varied from about 1.5 mph to 5.0 mph. With VSL signs displaying 65 mph, reductions in the average speeds are consistent at each location as shown in Figure 3-6. The standard deviation of the means at each counter location varied from about 0.5 mph to 1.0 mph. This means that at night drivers are more compliant to the reduced speed limit with VSL signs than with static work zone speed limit signs.

Figure 3- 5: Nighttime Average Speed July 10 to July 28



Ten samples were obtained to evaluate the effectiveness of static speed limit signs. Nighttime is defined as 7 pm to 8 am the next morning. The static limit at Counter 1 was 75 mph, while at Counters 2 through 5 it was posted as 65 mph. As you see in Figure 3-5, Counter 1 recorded average speeds between 70 to 75 mph. Between Counter 2 and 4, there is a general trend of decreasing average speeds in the work zone, however, at Counter 5, speeds actually seemed to increase. We can observe that there are wide variations of average speeds during the nighttime with static signage.

Figure 3-6: Nighttime Average Speed July 31 to August 5

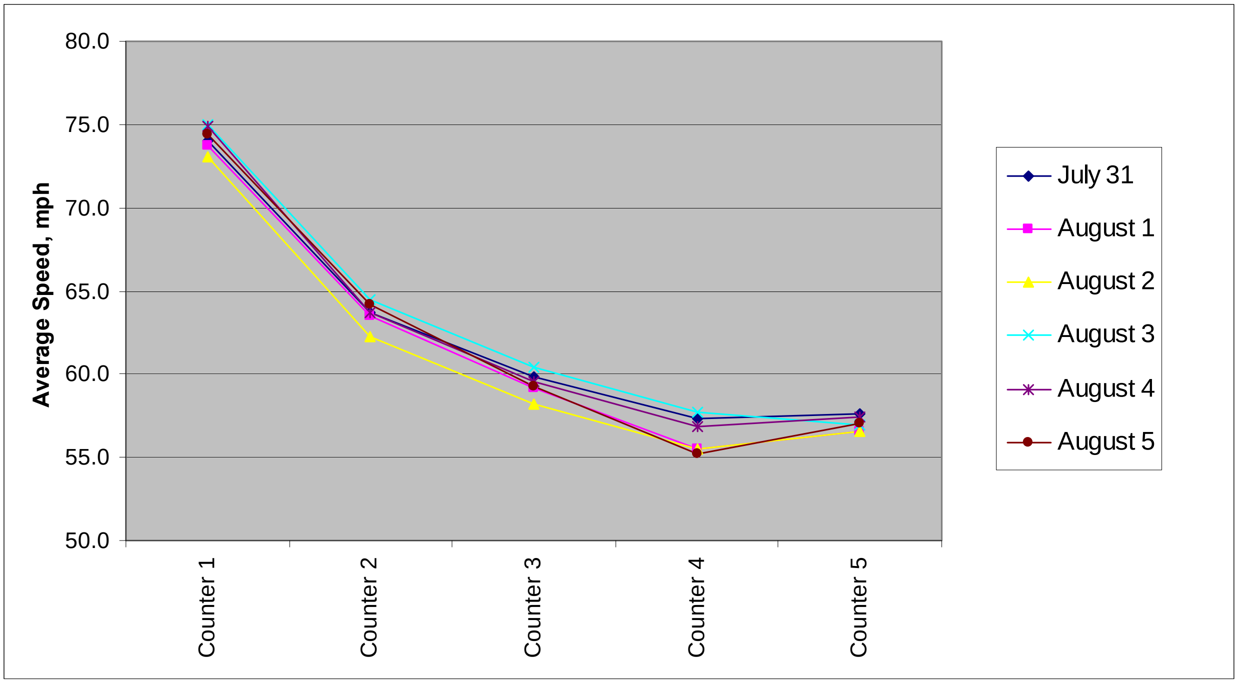


Figure 3-6 shows speed distribution during VSL sign usage and it does not have wide variation.

3.4.2. Daytime Average Speed

During the day from 9:00 AM to 7:00 PM, it seems average speeds are affected by the magnitude of work underway in the work zone as shown in Figures 3-7 and 3-8. Some of the days show that average speeds were significantly lower than the other samples. Figure 3-7 shows the trend in average speeds at each counter location with the static work zone speed limit sign and Figure 3-8 shows the trend in average speeds at each location with VSL signs. In general, speed changes are more consistent with VSL signs than with the static work zone speed limit signs.

Figure 3-7: Daytime Average Speed July 12 to 30, 65 mph Static Sign

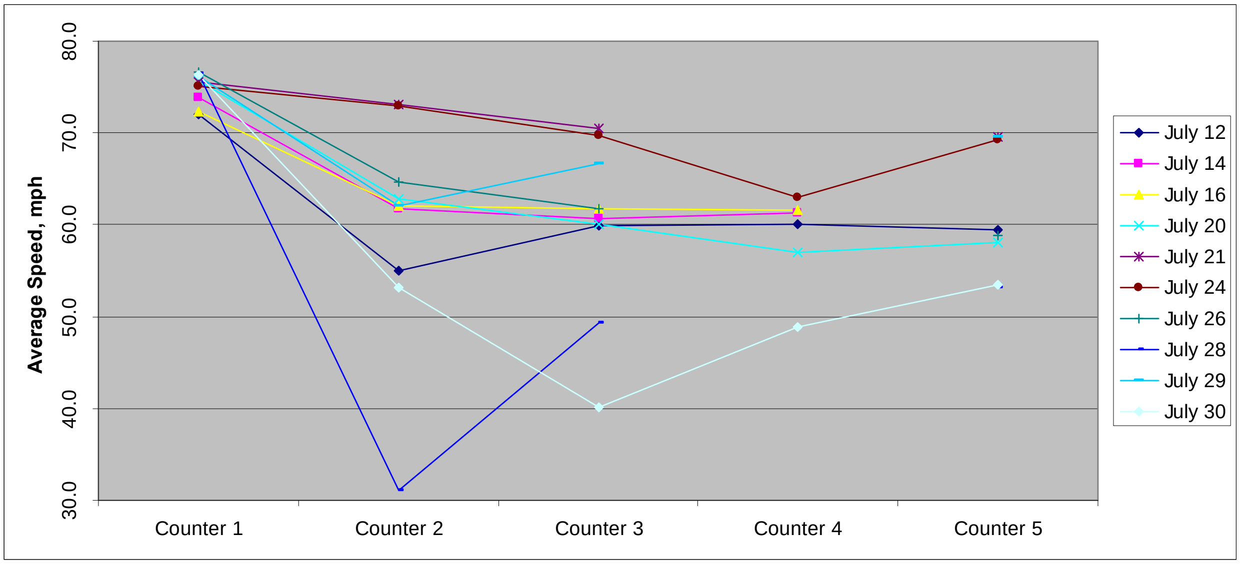


Figure 3- 8: Daytime Average Speed during 65 mph Variable Speed Limit Sign

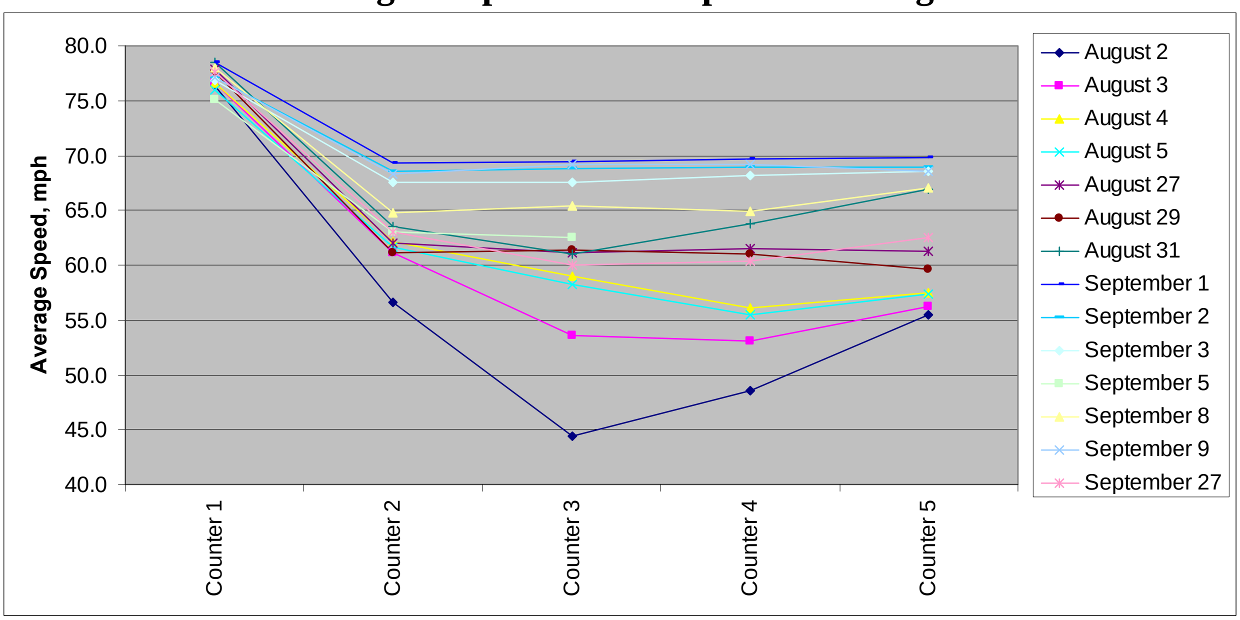
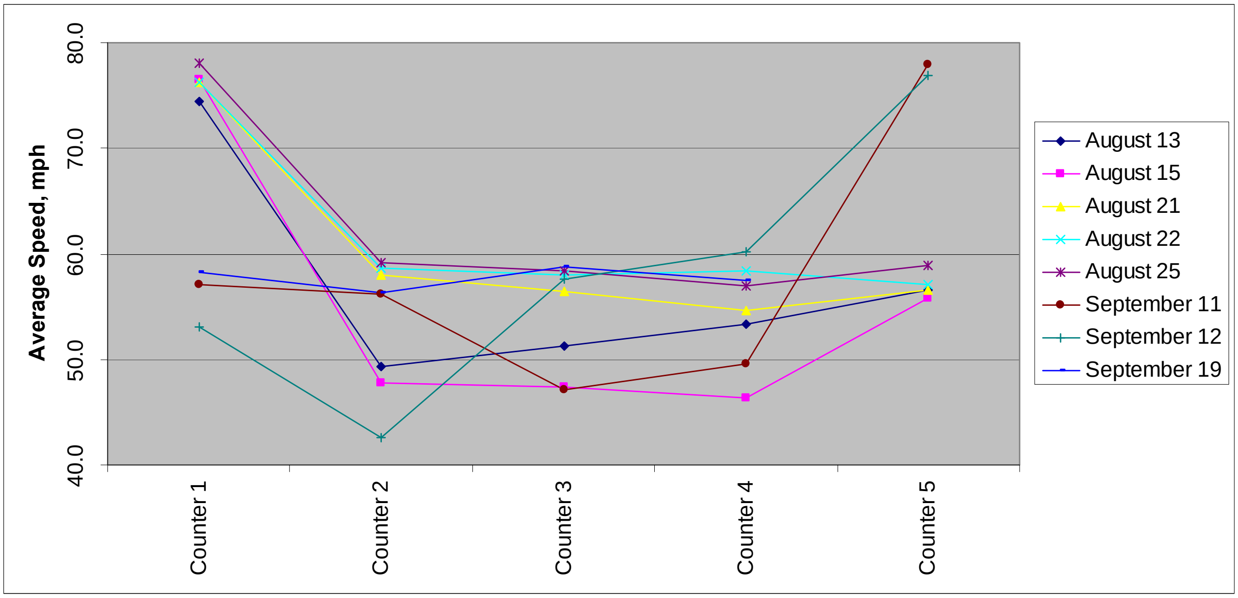


Figure 3-9 shows the trend in speed reduction with VLS signs displaying a 55 mph speed limit. Because the static work zone speed limit signs showing 55 mph speed limit was never shown to drivers, we cannot compare the benefit of VLS signs over static speed limit signs at the 55 mph speed limit level. What's obvious is that with 55 mph speed limit, drivers tend to speed up at the downstream end of the work zone as demonstrated by the average speeds at Counter 5. Four samples started with 75 mph at the upstream of the work zone and their speeds decreased to

50 to 60 mph and as shown in Figure 3-9, drivers maintained that speed level until they pass the active work zone.

Figure 3-9: Daytime Average Speed during 55 mph Variable Speed Limit Sign

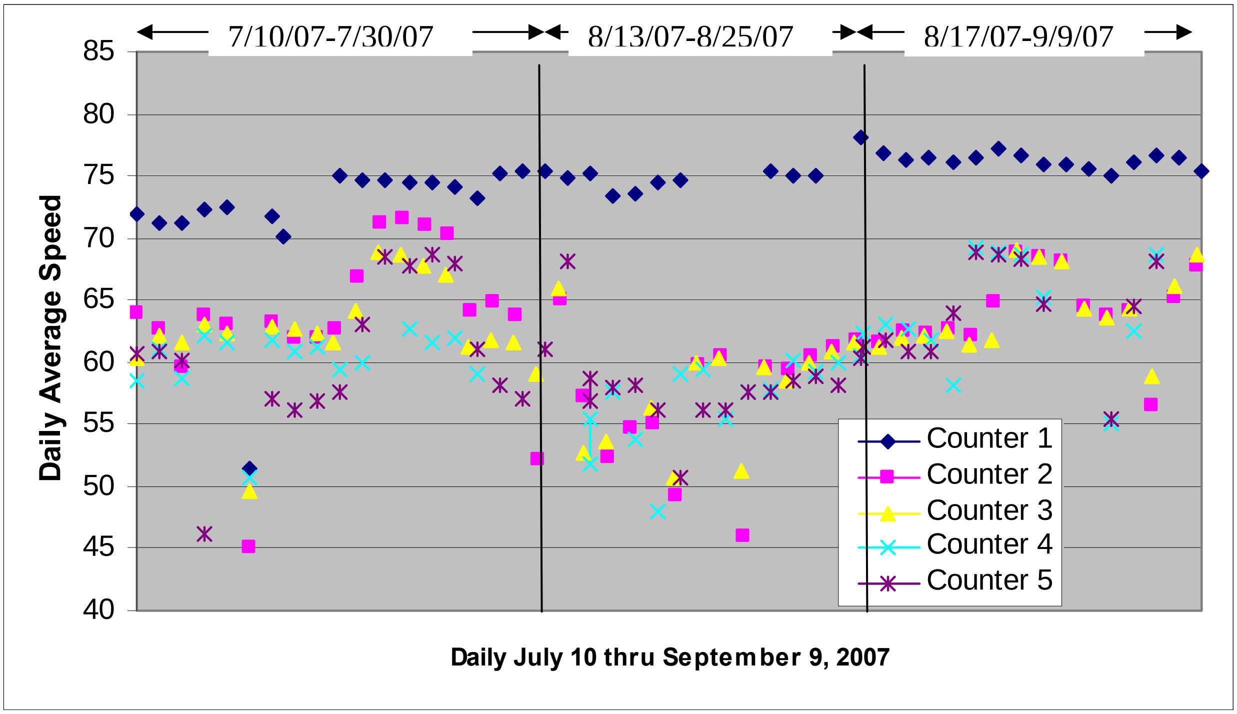


One day (September 12) started with a lower speed (53 mph) upstream of the work zone. It is likely a slow moving queue was forming upstream, drivers seemed to become impatient to the slow traffic and they began to speed up at Counter 3 and near Counter 5 they sped up to 77 mph

3.4.3. Selected Period Comparison

Due to missing data in early August and late September, three periods with complete data are examined further below. The first, from July 10 through July 30 has static signs; the second, August 13 through 25 has variable signs set to 55 mph during the day and 65 mph at night, and the third, August 27 through September 9, has variable signs set to 65 mph. Figure 3-10 shows the plots daily average speeds for these three periods.

Figure 3-10: Selected periods, Daily Average Speed

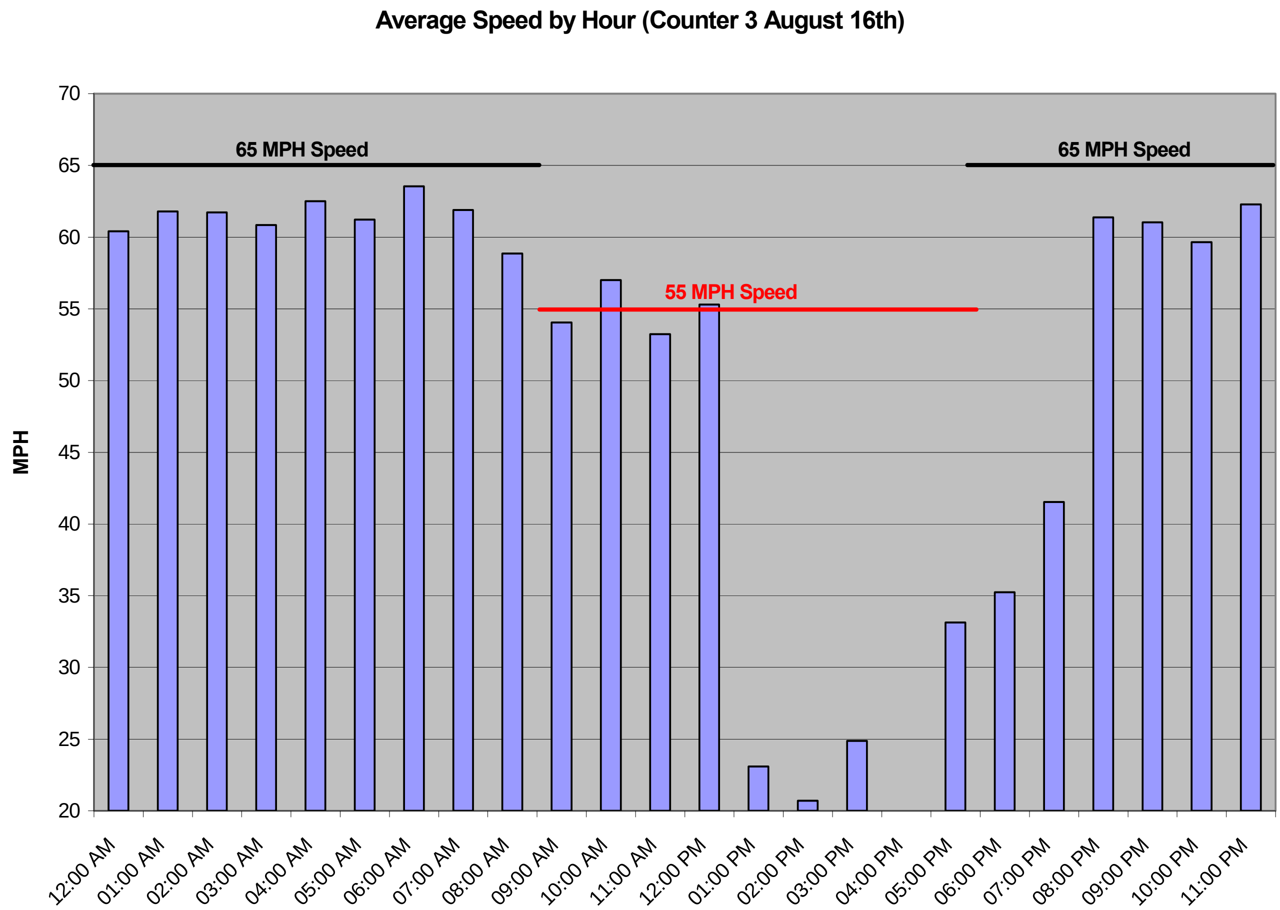


The daily average speed, by day for each counter location indicates that the location at Counter 1 experienced the highest average speeds. During the first period, when only the static speed limit signs were used, daily average speeds ranged from 45 to 73 mph at Counters 2 through 5 which were marked for 65 mph speed limit. During the second period, when VSL signs limited speed to 55 mph daytime and 65 nighttime, average speeds at these counters ranged from 46 to 62. During the third period, when Counters 2 through 5 followed VSL signs of 65 mph, average speeds ranged from 55 to 69.

Daily average speeds at Counter 1, located before the construction zone and signed throughout the test period by a static 75 mph sign, did not vary by more than 8 mph. Their lowest daily average occurred in July at 70 mph and the highest occurred in August at 78.

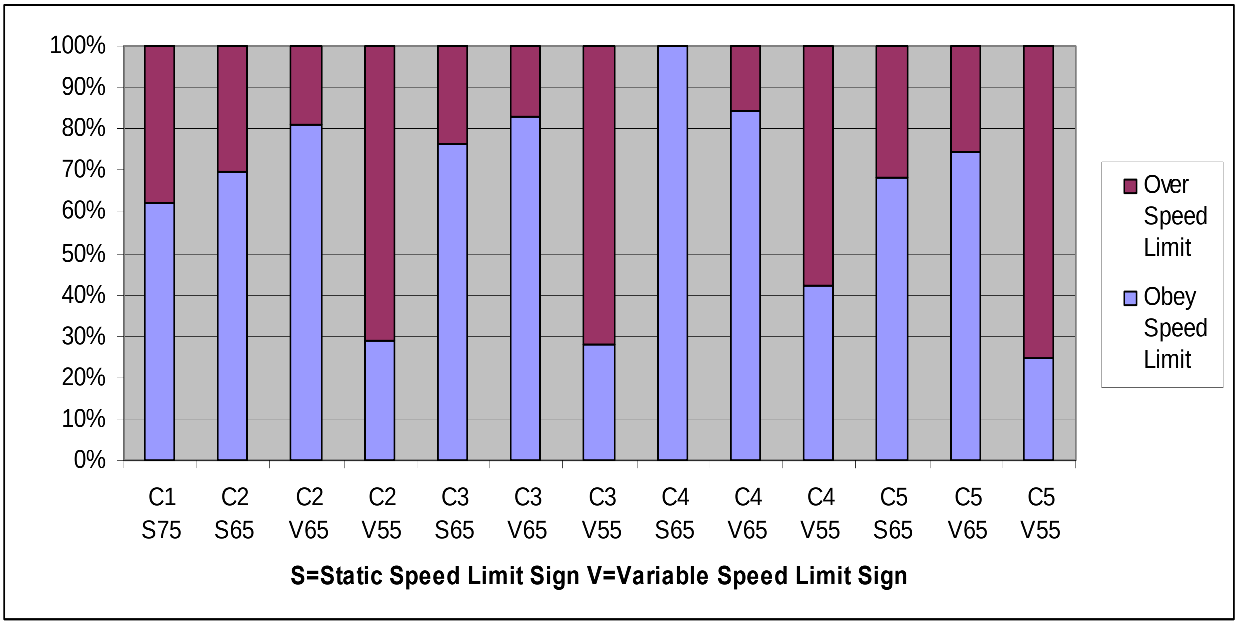
Due to construction activity in the work zone, at some times hourly speed slowed to congested traffic levels in the 10 to 30 mph range. The construction log kept at the test site, shows paving, equipment movement and other interruptions to the single lane open for travel. For example on August 16, paving in the vicinity of Counter 3 occurred and is reflected in the data. On some heavy travel days, particularly on Sunday afternoons, speed reduction can be observed in the data at all counters, even at Counter 1 upstream of the construction zone.

Figure 3-11: Average Speed for Counter 3, August 16



3.5 Speed Limit Compliance

Figure 3-12: Speed compliance by hourly average speed



If you take the average speed of travel, for each hour, at each data collection point, for the entire length of the study, you can compare the observed speed to the posted speed limit. Figure 3-12 shows, by counter and by the type of posted speed limit (S for Static or V for Variable), the percentage of vehicles obeying the speed limit. At Counters 2, 3 and 5, the Variable sign at 65 MPH has greater compliance than the Static 65 MPH signs. You can see this when comparing C2 S65 to C2 V65, C3 S65 to C3 V65, and C5 S65 to C5 V65. At Counter 4, the Static sign had 100% compliance for hourly average speed of travel. At all counters, however, the variable sign posted at the 55 mph limit, has the worst compliance (C2 V55, C3 V55, C4 V55, C5 V55).

3.6 Statistical Analysis

This data must be analyzed to insure it is relevant and significant rather than randomly obtained. Using a means test for randomly selected days and counters, the confidence level of the mean is 95%. A Z Test is a Normal Approximation Test and can be used to compare the data changes to what might occur under a Normal Distribution. A Z test was performed for all counters on several days under each signing condition to understand if differences in mean traveling speed are because of changes in signing or due to random factors. One-way analysis was used because we are solely interested in speed reduction not in speed change which can increase or decrease, i.e. the critical z-value is 1.65.

For a 95% confidence level, Z Test critical value for a normal distribution is 1.65, which is based on being within two standard deviations of the mean value. In other words, if the calculated Z value for each data set is greater that 1.65, than the change in mean speed is due to a change in conditions and not randomness.

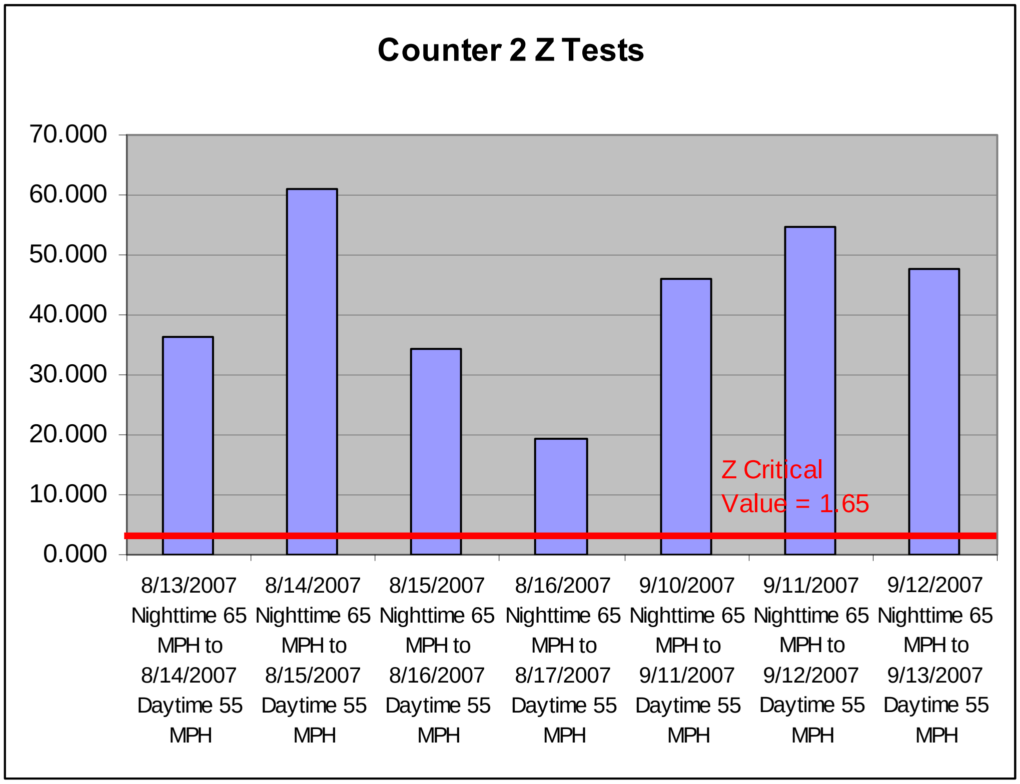
Z Tests were performed at counter 2 and counter 3 locations on days in which the speed limit varied between 65 MPH and 55 MPH. Z Tests performed on counter 2 are listed in the table and chart below.

Table 3-2: Counter 2 Z Tests

Z Critical 1.65	Mean Speed Difference	Calculated Z-Value
8/13/2007 Nighttime 65 MPH to 8/14/2007 Daytime 55 MPH	7.2	36.389
8/14/2007 Nighttime 65 MPH to 8/15/2007 Daytime 55 MPH	11.8	60.998
8/15/2007 Nighttime 65 MPH to 8/16/2007 Daytime 55 MPH	6.1	34.293
8/16/2007 Nighttime 65 MPH to 8/17/2007 Daytime 55 MPH	3.1	19.334
9/10/2007 Nighttime 65 MPH to 9/11/2007 Daytime 55 MPH	7.2	46.007
9/11/2007 Nighttime 65 MPH to 9/12/2007 Daytime 55 MPH	10.8	54.632
9/12/2007 Nighttime 65 MPH to 9/13/2007 Daytime 55 MPH	7.1	47.799

For counter 2, every time the posted speed limit changes the mean speed lowered. The calculated Z-values were all over 1.65 which means that the difference in mean speed is due to the signing changes and not simply randomness.

Figure 3-13: Counter 2 Z Test Values by Day



Z Tests performed on counter 3 are similar to those of counter two and every tested scenario has a z-value greater than 1.65

Z tests can also be used to test if the difference in mean speed between counter 1, located before the construction (75 MPH), and counter 2, located in the construction zone (65 MPH) is due to signing differences or a random occurrence. Table 3-4 displays the mean speed difference between counters 1 and 2, and counters 2 and 3. The calculated z-values of both indicate that the 6.2 MPH reduction is mean speed between counters 1 and 2 is due to outside factors, while the 0.1 MPH difference between counters 2 and 3 is due to randomness.

Table 3-4: Z Tests between Counter 1 and 2

Z Critical 1.65	Mean Speed Difference	Calculated Z-Value	
75 mph to 65 mph by regular static 65 mph sign (counter 1 to counter 2)	6.2	46.726	Difference in Mean Speed due to Signing
65 mph to 65 mph by regular static 65 mph sign (counter 2 to counter 3)	0.1	0.905	Random Difference in Mean Speed

4 CONCLUSIONS AND RECOMENDATIONS

Study Result

VSL signs resulted in average speeds which were lower than the static signs. In evening conditions, where VSL were set to 65 MPH and no construction activity was in place, VSL signs resulted in average speeds which were statistically lower than static speed limits signs through the construction zone. Daytime conditions showed greater variation due to the level of congestion which occurred related to the construction activity and lane closures. However, even dismissing the data impacts of low speeds during daytime congestion, VSL signs showed greater compliance over static speed limit signs.

A potential concern of lower speed limits resulting in a greater variation in driver speeds due to some drivers obeying the speed limit and other drivers traveling at "comfortable" speeds did not occur. VSL signs reduced both the average speed and the variation in speed. During evening conditions with the VSL sign set to 65 MPH, the standard deviation of speeds reduced by between 1.5 to 5.0 MPH.

Although accident data was not directly collected, it can be inferred from the reduction in average speeds and deviation in speeds that the VSL signs will result in reduced work zone accidents. This accident reduction would be the result of providing drivers accurate speed restrictions based on the real time construction conditions resulting in a "trust" level between travelers and the posted speed limit. Through this trust, drivers are impacted less during non-construction activities with slight speed reductions and impacted more during actual construction with greater speed reductions appropriate for the conditions of the road.

UDOT Policies

UDOT Policy 06C-61, Work Zone Speed Limits, allows work zone speed limits to temporarily be reduced by 10 MPH on roads greater than or equal to 60 MPH, or 5 MPH on roads less than 60 MPH. Changes to this policy are possible with the condition is limited to one-time 20 calendar days (10 days plus a 10 day extension) or through the process of a Traffic Engineering Order (UDOT Policy 06C-5). These policies allow limited applications for VSL signs due to the relatively lengthy Traffic Engineering Order process. Revised policies which facilitate the application of VSL signs should be developed.

Such revised policies may be written to specifically apply to the use of VSL signs. These policies could continue to limit the non-construction application of work zone area construction zones to the present speed reductions. Intense construction activity could be defined such as active construction and construction personnel within 10 lateral feet of the travel lane without the use of concrete (Jersey) barriers, or similar definition. During intense construction activity, speeds could be temporarily reduced by up to 20 MPH on high speed (60 MPH+) roads and 10 MPH on lower speed roads. These values have been based on those using in this single study, and may be subject to further study and review by the Department.

Other Work Zone standards have not been reviewed as part of this research. However, this research suggests that the travel speeds could increase through the construction zone such that the fifth traffic counter observed speed increases above the posted 55 MPH VSL, especially when entry speeds are already low. Drivers may try to make up the delay caused at the upstream of or the entry to the work zone. VSL signs should be placed to meet the spacing standards of other static (work zone) signs, which may result in the need for additional VSL signs and higher construction costs.

Future Specifications

The use of VSL signs appears to represent promising technology which can result in safer work zones and more efficient speed regulations. The application of VSL signs in other states is not limited to work zones. Applications in Utah could include permanent signs which vary the speed based on prevalent weather conditions, traffic loads, or truck loads. No immediate application has been researched, but UDOT is advised to not limit the scope of VSL signs to work zones and should continue to watch the state-of-the-practice usage.

Specifications are also expected to advance in practice as additional technologies become available. Precision Solar Controls, Inc. recently released a radar speed data collection counter to accompany its variable message signs. Traffic counters would allow the use of their data for research as additional VSL signs are purchased and put into operation by UDOT.

5 Appendix

5.1 References

American Association of State Highway and Transportation Officials (ASSHTO), 2004. *A Policy on Geometric Design of Highways and Streets*.

Minnesota Department of Transportation, 2007. *Field Evaluation of A Variable Advisory Speed Limit System for Reducing Traffic Conflicts at Work Zones*. Transportation Research Board Annual Meeting 2007 Paper #07-2551.

Robinson, Mark. *Examples of Variable Speed Limit Applications.* Presentation given at the Speed Management Workshop held in conjunction with the 79th Annual Meeting of the Transportation Research Board. January 2000. http://safety.fhwa.dot.gov/fourthlevel/ppt/vslexamples.ppt (Accessed December 2007).

TRB January 2000. *Speed Management Workshop*, http://safety.fhwa.dot.gov/tools/docs/vslexamples.ppt (Accessed December 2007).

U. S. Department of Transportation Federal Highway Administration, December 2004. *A Field Test and Evaluation of Variable Speed Limits in Work Zones*.

Utah Department of Transportation. Policy 06C-5, 06C-25 and 06C-61.

Purpose

The purpose of this policy is to define the process for the establishment of speed limits on state highways. See Policy 06C-61 for the establishment of temporary speed limits in work zones.

Policy

It is the policy of the Utah Department of Transportation to establish speed limits on state highways on the basis of an engineering and traffic investigation in accordance with the most recent edition of the Manual on Uniform Traffic Control Devices (MUTCD). Speed zone studies will be conducted upon request of the Region Director/District Engineer, the Region Traffic Engineer, or other recognized authority. In conducting a speed zone study, input from local government officials will be considered. Establishment of speed limits may not violate the provisions of Sections 41-6-46 and 41-6-47 of the Utah Code Annotated.

The statutory speed limit shall be based on the 85th percentile speed rounded to the nearest 5 mph increment, and giving consideration to:

1. Road surface characteristics, shoulder condition, grade, alignment, and sight distance.

2. Roadside development and culture, and roadside friction.

3. Safe speeds for curves or hazardous locations within the zone.

4. Pedestrian activity, parking practices, and other traffic.

5. Reported accident experience for the most recent 3 year period.

In establishing the statutory speed limit, consideration may be given for a speed limit below the 85th percentile speed based on the above factors. Any reduction below the 85th percentile speed shall not exceed 10 mph when the 85th percentile speed is greater than 45 mph and 5 mph when the 85th percentile speed is less than, or equal to, 45 mph. The reduced speed limit shall be reviewed with local authorities.

Whenever the speed limit has been reduced below the 85th percentile speed as a result of the engineering and traffic investigation, another study will be made from six to twelve months later. If necessary, the speed limit will then be adjusted to ensure that it is not more than 5 mph below the 85th percentile speed. Local authorities will be advised before any changes are made.

In conducting the study, if no reduction of the speed limit is recommended and local authorities are not satisfied with the results of the Department study, an appeal process is available and is described later in this policy/procedure. All appeals must be substantiated by facts and reliable data.

Procedures

Establishment Of Speed Limits On State Highways UDOT 06C-25.1

Responsibility: Region Director/District Engineer or Region Traffic Engineer

Actions

1. Region Director/District Engineer or Region Traffic Engineer receives a request from a local government to perform a speed zone study. This request from the local government should include reasons why it is felt that the speed limit should be changed together with recommendations as to what the speed limit should be.

2. Requests the Engineer for Traffic and Safety to conduct the necessary study.

Responsibility: Engineer for Traffic and Safety

3. Upon receipt of request from a Region/District for a speed limit study, requests that the Traffic and Safety Studies Engineer performs the necessary study.

Responsibility: Traffic and Safety Studies Engineer

4. Initiates field study to include three year accident history, roadway geometry, roadside developments throughout the highway segment, pedestrian activity, school crossings, 85th percentile speed, and other considerations.

5. Evaluates data to determine appropriate speed limit in accordance with MUTCD.

6. Prepares study report and submits recommendations with appropriate supporting data to the Region Director/District Engineer.

Responsibility: Region Director/District Engineer

7. Informs local government of study results. Schedules meeting with local government officials, if necessary. Requests Engineer for Traffic and Safety to issue appropriate T.E.O.

Responsibility: Local government agency (appeal process)

8. May appeal the speed study recommendations to the Department Executive Staff. All appeals shall be based on violation of Department Policy or MUTCD Standards.

Responsibility: Engineer for Traffic and Safety

9. Issues required T.E.O.

Responsibility: Region Director/District Engineer

10. Executes necessary steps to comply with T.E.O. including preparation and placement of new speed limit signs or relocation of existing signs.

Work Zone Speed Limits UDOT 06C-61

Effective: August 14, 1996 Revised: August 24, 2005

Purpose

The purpose of this policy is to define the proper process for the establishment of temporary regulatory speed limits in work zones on all state highways.

Policy

Existing speed limits confirmed by a Traffic Engineering Order (TEO) shall remain in effect through work zones on state highways except where an unusual or serious hazard would be created by the retention of the existing speed limits. When such a condition occurs, the speed limit may be temporarily reduced 10 MPH on roads greater than or equal to 60 MPH, or 5 MPH on roads less than 60 MPH.

When temporary conditions occur regulatory speed changes shall only be used during impacted times and in impacted areas as shown in the option below:

1. A temporary regulatory speed limit may be set by the Region Director, after consultation with the Region Traffic Engineer when conditions experienced in the field by either maintenance or construction work forces may create a hazard. The temporary regulatory speed limit shall be in effect no longer than 10-calendar days. A one-time 10-calendar day extension of the temporary regulatory speed limit may be granted by the Region Director, after consultation with the Region Traffic Engineer. If the temporary regulatory speed limit, established by the Region Director, is to stay in effect longer than 20-calendar days, a formally approved TEO will be required from the Division of Traffic and Safety.

2. A temporary regulatory speed limit, within a project, may be established as a part of the traffic control plan with a formally approved TEO from the Division of Traffic and Safety. Temporary regulatory speed limit signs shall not be erected until all appropriate work zone signs have been placed in accordance with the approved traffic control plans.

Definitions

Traffic Engineering Order (TEO)

A Traffic Engineering Order (TEO) is a document that specifies the authority to establish specific traffic regulations pertaining to directional movements, speed limits, parking restrictions, and railroad grade crossing exemptions. See Policy UDOT 06C-05 for further information regarding TEOs.

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Procedures

Existing Work Zones UDOT 06C-61.1

Responsibility: Resident Engineer/Construction/Maintenance Supervisor/Permits Officer

Actions

1. Determines the need for a temporary regulatory speed limit.
2. Prepares recommendation for all justified, temporary regulatory speed limit, ensuring all alternatives including positive protection have been considered, and submits it to the Region Traffic Engineer for consideration.

Responsibility: Region Traffic Engineer

3. Considers recommendations and submit to the Region Director with comments.

Responsibility: Region Director

4. Considers recommendation together with comments of Region Traffic Engineer and approves request if such action is determined to be appropriate. Said approval shall be for a 10 calendar day period.

Responsibility: Resident Engineer/Construction/Maintenance Supervisor/Permits Officer

5. Shall determine impacted areas and impacted times and make any signing changes that are necessary. This may require removing or covering any sign that is not appropriate or consistent with the construction impact.

Responsibility: Region Traffic Engineer

6. Periodically reviews work zone with temporary regulatory speed limit to make sure conditions are acceptable. Unacceptable conditions may require changing the temporary regulatory speed limit. Also determines if a one-time 10-calendar day extension to the original temporary regulatory speed limit is appropriate.
7. Makes recommendation to the Region Director regarding a 10-calendar day extension or to request the issuance of a TEO to cover a longer period.

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Procedures

Existing Work Zones UDOT 06C-61.1

Responsibility: Region Director

8. Considers recommendation of Region Traffic Engineer and, if appropriate, approves request for a 10-calendar day extension or transmits a request for a TEO to the Division of Traffic and Safety.

Responsibility: Traffic and Safety Division

9. For justifiable requests, issues a TEO for a temporary regulatory speed limit within 7-calendar days of receiving said request.

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Procedures

Traffic Control Plan Development UDOT 06C-61.2

Responsibility: Project Design Engineer

Actions

1. In consultation with the Region Traffic Engineer, makes a determination that a temporary regulatory speed limit is appropriate, all alternatives including positive protection have been considered, and the temporary speed limit is necessary for a project in design.

Responsibility: Region Traffic Engineer

2. Reviews traffic control plan submitted by contractor.
3. Considers recommendation and submits request to the Region Director with comments.

Responsibility: Region Director

4. Considers recommendation of Region Traffic Engineer and transmits a request for a TEO to the Division of Traffic and Safety.

Responsibility: Traffic and Safety Division

5. Approves requests and issues a TEO for a temporary regulatory speed limit within 7-calendar days of receiving said request.

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